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EFFECT OF INTERFACIAL PHENOMENA ON CONTACT LINE HEAT
TRANSFER-III(U) RENSSELAER POLYTECHNIC INST TROY N Y
DEPT OF CHEMISTRY P C WAYNER 20 OCT 87
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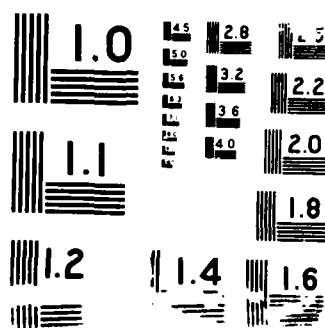
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The heat transfer characteristics of the contact line region of an evaporating thin liquid film were studied experimentally and theoretically. The effects of composition and temperature gradients on surface shear were analyzed and the results were successfully compared with previously reported experimental trends. The use of a constant vapor pressure boundary condition allowed the relative effects of surface tension, composition and temperature on fluid flow to be mapped. A small heat transfer cell was designed, built and used on the scanning stage of a scanning microphotometer. The unique use of a microphotometer allows the microscopic details to be measured.

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Dr. Mitat Birkan

22b. TELEPHONE (Include Area Code)

(202) 767-4937

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2. STATEMENT OF RESEARCH OBJECTIVES

The following figure which was taken from our previously submitted annual reports outlines the general three year objectives of the project.

FIGURE 1

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INTERFACIAL HEAT TRANSFER CONTACT LINE REGION

Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

GOAL

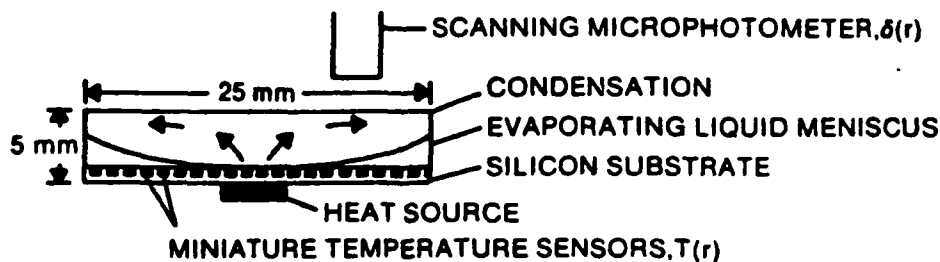
UNDERSTANDING OF TRANSPORT MECHANISMS IN EVAPORATING THIN LIQUID FILM (THICKNESS $< 10^{-5}$ m).

GENERAL PRINCIPLE

HEAT, MASS, AND MOMENTUM TRANSFER ARE CONTROLLED BY INTERFACIAL PHENOMENA RESPONDING TO GRADIENTS IN THE THICKNESS, TEMPERATURE AND CONCENTRATION.

TECHNIQUES

1. MEASURE LIQUID THICKNESS PROFILE, $\delta(r)$, AS A FUNCTION OF BULK CONCENTRATION AND EVAPORATION RATE IN NEW CIRCULAR MINIATURIZED HEAT TRANSFER CELL USING SCANNING MICROPHOTOMETER.



2. MEASURE SUBSTRATE TEMPERATURE PROFILE, $T(r)$, USING SMALL TEMPERATURE SENSORS.



3. COMBINE THE FOLLOWING CONCEPTS INTO HEAT TRANSFER SUCTION POTENTIAL MODEL: DISJOINING PRESSURE, FLUID MICROSTRUCTURE, SURFACE TENSION, SURFACE SHEAR STRESS, APPARENT CONTACT ANGLE, $\delta(r), T(r)$.

3. STATUS OF RESEARCH

The scientific accomplishments are detailed in the publications listed in Section (4) and outlined in the following paragraphs.

I) Design and Build a New Heat Transfer Cell

A new small circular heat transfer cell was designed and built during the grant. A cross-sectional diagram and photographs of the cell were presented in our first annual report. A sketch is presented in Figure (1). Details of its use are presented in publication (4b & 4e) which are listed below. The use of a small circular design eliminates the edge effects and reduces extraneous bulk effects. In this way we can focus on the heat transfer processes occurring in the contact line region. The interference fringes which result from the interference of the light waves reflected from the liquid-vapor interface with those reflected from the liquid-solid interface were scanned "in-situ" with a scanning microphotometer. The measured fringe pattern gives the thin film thickness profile which was used to obtain the capillary pressure and the disjoining pressure gradients. The results of these calculations are also detailed in publications (4b) and (4e). The cell is currently being redesigned for future use.

II) Test the Cell Design by Obtaining Heat Transfer Data

The heat transfer cell was tested for its response to the following variables: the external heat input, the bulk liquid composition, the external heat sink, and the level of non-condensibles in the vapor space. We note that since the cell is passive in that the interfacially induced flow rates are controlled by the temperature distribution on the surface of the cell (external heat input and external heat sink) the selection of the cell dimen-

sions and the operating variables are critical. Our initial tests indicated that the cell design dimensions were approximately correct in that the internal flow fields were desirable. The data obtained using decane and hexane were analyzed to determine the general operating characteristics of the cell. The results are also presented in publications (4b and 4e).

III) Develop Small Temperature Sensors

To measure the physical parameters needed to characterize and model heat transfer processes occurring on a miniature scale, devices whose dimensions are on the order of the process itself were developed. One ideal way to fabricate such devices is to use miniature solid state processing techniques. To measure the temperature gradient along the evaporating film, various miniature thin film thermistor sensors and circuits were manufactured at the Rensselaer Polytechnic Institute and its Center for Integrated Electronics (CIE). We were successful in manufacturing small ($10\text{ }\mu\text{m} \times 10\text{ }\mu\text{m}$) thermistors. The details of the fabrication process and calibration are presented in Publication (4g). The use of the sensors in an active heat transfer cell is currently being demonstrated.

Abstract from (4g) (currently under review by J. Electrochem. Soc.).

A linear thin-film array of silicon carbide thermistors has been developed to measure temperature profiles near the contact line of an evaporating liquid meniscus. The array consists of 80, $10\text{ }\mu\text{m} \times 10\text{ }\mu\text{m}$ square silicon carbide thermistors on a 3"-diameter, single crystal of silicon. The devices are spaced at 50- μm , 250- μm , and 1000- μm intervals along the wafer. Temperature data are obtained through the use of an external electronic data acquisition system. This arrangement enables an accurate evaluation of the heat flux

occurring in an evaporating thin liquid film, and it should also be suitable for temperature measurements in many other situations.

IV) Modeling of Suction Potential at the Contact Line

In general, the physicochemical phenomena associated with fluid flow in an evaporating thin film of an ideal binary mixture in the contact line region were modeled. The details are presented in Publications (4a, 4c, 4d, 4f) which are listed below. Within these studies, the effect of composition and temperature gradients on surface shear were evaluated. Using a constant vapor pressure boundary condition based on Raoult's Law, significant new insights concerning the effect of liquid composition on enhanced fluid flow due to surface shear in the contact line were developed. The results were successfully used to qualitatively describe the trends experimentally observed in previous experimental studies.

The resulting equation for the mass flow rate given in Publication [4a] is

$$\Gamma = \frac{\delta^3}{3\nu} \left[\underset{\text{(I)}}{1.5\delta^{-1}\sigma'} + \underset{\text{(II)}}{\delta^{-n}B'} + \underset{\text{(III)}}{K\sigma'} + \underset{\text{(IV)}}{\sigma K'} - \underset{\text{(V)}}{nB\delta^{-(n+1)}\delta'} + \underset{\text{(VI)}}{\rho g\delta'\cos\theta} + \underset{\text{(VII)}}{\rho g\sin\theta} \right] \quad (1)$$

wherein:

$\delta[=]$ film thickness

$K[=]$ curvature

$\sigma[=]$ surface tension

$\rho[=]$ density

$B[=]$ dispersion constant

$g[=]$ gravitational constant

$\theta[=]$ angle of inclination

The prime refers to differentiation with respect to x . In this equation Terms (I-III) are functions of the temperature and concentration gradients, whereas Terms (IV-VII) are functions of the film profile. Terms (II & V) are associated

with the disjoining pressure. The significance of the results in the publications is that additional insights concerning the conditions under which Terms (I-III) are important were developed. Although the film profile can be easily measured optically, the concentration and temperature gradients in a region less than 1 mm in length cannot be easily obtained experimentally. Therefore, extensive modeling of the fluid flow mechanisms dependent on the concentration and temperature gradients is needed. We note that although the new temperature sensors allow the temperature field to be measured much more accurately than before some modeling of the temperature gradient will always be necessary. The model presented in the publications was primarily concerned with Terms (I-III). The results presented in these references demonstrated that the effect of surface shear on fluid flow can change sign in a distilling thin film as it flows towards the heat source along a constant vapor pressure line when $\sigma_2 > \sigma_1$ (subscript 2 refers to the less volatile component of a binary mixture). Assuming that the flow starts in a region where surface shear enhances the flow towards the heat source, $\frac{d\sigma}{dT} > 0$, a composition is reached in the flowing film at which flow reversal can occur in the film. The location of the sign reversal is a function of the concentration, the temperature level, and the difference in the surface tensions of the components of the binary mixture. Confirmation of this prediction in a designed set of experiments would verify the use of a constant vapor pressure boundary condition in the model. In addition the approximate value of the zones of minimum surface shear would be known. This then allows a set of conditions to be selected so that the effect of these terms would be minimum in experiments designed to evaluate Terms (IV & V). Previously, these conditions were not quantitatively known to this degree.

4. PUBLICATIONS

- 4(a) Wayner, P.C., Jr. and Parks, C.J., "Effect of Liquid Composition on Enhanced Flow Due to Surface Shear in the Contact Line Region: Constant Vapor Pressure Boundary Condition," in Multiphase Flow and Heat Transfer, Editors: V.K. Dhir, J.C. Chen, and O.C. Jones, ASME HTD - Vol. 47, pp. 57-63 (1985).
- 4(b) Kiewra, E. and Wayner, P.C., Jr., "Small Scale Thermosyphon for the Immersion Cooling of a Disc Heat Source," in "Heat Transfer in Electronic Cooling-1986", ASME HTD-Vol. 57, Editor: A. Bar Cohen, pp. 77-82 (1986).
- 4(c) Parks, C.J. and Wayner, P.C., Jr., "Fluid Flow in an Evaporating Meniscus of a Binary Mixture in the Contact Line Region: Constant Vapor Pressure Boundary Condition", Preprint # 39e, 1985 Annual Meeting of American Institute of Chemical Engineers, Chicago, IL, Nov. 10-14 (1985).
- 4(d) Parks, C.J. and Wayner, P.C., Jr., "Surface Shear Near the Contact Line of a Binary Evaporating Curved Thin Film", A.I.Ch.E. Journal, 33, 1-10 (1987).
- 4(e) Sujanani, M., Kiewra, E., and Wayner, P.C., Jr., "A Small Scale Thermosyphon Heat Exchanger", Proceedings of Sixth International Heat Pipe Conference, Grenoble, France, May 28-29 (1987), 2, 352-358.
- 4(f) Parks, C.J. and Wayner, P.C., Jr., "A Model for the Transport Phenomena Associated with a Two-Component Meniscus Evaporating into a Multicomponent Vapor", A.I.Ch.E. Symposium Series 257, 83, 122-127 (1987).
- 4(g) Kiewra, E. and Wayner, P.C., Jr., "The Development of a Thin-Film Silicon Carbide Thermistor Array for Determining Temperature Profiles in an Evaporating Liquid Film", Submitted to J. of the Electrochemical Society.
- 4(h) Gerhardt, L. and Wayner, P.C., Jr., "Interfacial Phenomena in Change-of-Phase Heat Transfer: Low Concentration Polymer Solutions", Submitted to ASLE for publication.

5. PROFESSIONAL PERSONNEL

- 5(a) Peter C. Wayner, Jr., Principal Investigator
Edward Kiewra, Graduate Research Assistant
Muralidhar Tirumala, Graduate Research Assistant (Part-time)
Manoj Sujanani, Research Assistant

Part-time

MS Degree: Linda J. Gerhardt, "Evaporative Heat Transfer in the Contact Region: Low Concentration Polymer Solution", May, 1986.
[Partial support received from this grant].

6. INTERACTIONS

- 6(1a) Wayner, P. C., Jr., "Effect of Interfacial Phenomena on Contact Line Heat Transfer", Paper 58, 1985 AFOSR/AFRPL Chemical Rocket Research Meeting, Lancaster, CA, March 18-25, 1985.
- 6(1b) Wayner, P.C., Jr., and Parks, C.J., "Effect of Liquid Composition on Enhanced Flow Due to Surface Shear in the Contact Line Region: Constant Vapor Pressure Boundary Condition," Presented at 23rd National Heat Transfer Conference, Denver, CO, Aug. 4-7, 1985.
- 6(1c) Parks, C.J., and Wayner, P.C., Jr., "Fluid Flow in an Evaporating Meniscus of a Binary Mixture in the Contact Line Region: Constant Vapor Pressure Boundary Condition," Preprint # 39e, 1985 Annual Meeting of American Institute of Chemical Engineers, Chicago, IL, Nov. 10-14, 1985.
- 6(1d) Wayner, P.C., Jr., "Effect of Interfacial Phenomena on Contact Line Heat Transfer", Paper 12, AFOSR/AFRPL Chemical Rocket Research Meeting, Lancaster, CA, Sept. 9-11 (1986).
- 6(1e) Parks, C.J. and Wayner, P.C., Jr., "A Model of Surface Shear in a Binary Evaporating Thin Film", Presentation at 60th Colloid and Surface Science Symposium, Georgia Institute of Technology, Atlanta, GA, June 15-18 (1986).
- 6(1f) Kiewra, E. and Wayner, P.C., Jr., "Small Scale Thermosyphon for the Immersion Cooling of a Disc Heat Source", Presentation at AIAA/ASME 4th Thermophysics and Heat Transfer Conference, Boston, MA, June 2-4 (1986).
- 6(1g) Parks, C.J. and Wayner, P.C., Jr., "A Model for the Transport Phenomena Associated with a Two-Component Meniscus Evaporating into a Multicomponent Vapor", Presentation at the 24th National Heat Transfer Conference, August 10-12, 1987, Pittsburgh, PA.
- 6(1h) Sujanani, M., Kiewra, E.W., and Wayner, P.C., Jr., "A Small Scale Thermosyphon Heat Exchanger", Presentation at the 6th International Heat Pipe Conference, May 25-27, 1987, Grenoble, France.
- 6(2a) Meeting with E.T. Mahefkey (AFWAL/POOC) J.E. Beam (AFWAL/POOC), and R. Ponnappan at Wright-Patterson Air Force Base, Ohio, 22 July 1985. Discussed research direction and general problems associated with heat pipe research at Wright-Patterson Air Force Base.
- 6(2b) Meeting with E.T. Mahefkey (AFWAL/POOC), J.E. Beam, (AFWAL/POOC), L. Chow, and S. Patterson at Wright-Patterson Air Force Base, Ohio, 18 Sept. 1986. Discussed research direction and general problems in thermal management.
- 6(2c) AFOSR/ONR Contractors Meeting on Combustion and Rocket Propulsion Meeting, Pennsylvania State University, 22-26 June 1987. General discussions with attendees.

7. GENERAL APPLICATIONS

Use of research heat transfer cell described in 4(e) as small thermosyphon for immersion cooling of electronic heat source.

Use of sensors described in 4(g) as high resistance thermistors.

The results presented in (4a) can be used to determine the direction of surface shear induced flow.

8. None

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